GLACIAL CLIMATE.[1]

EVERY fragment of evidence, which can serve to show us the character of the climatal conditions during the last glacial period, is so important that I venture to present certain facts which, so far as I am aware, have hitherto escaped attention. The evidence I mean to discuss is found in America and Europe in the regions immediately south of the glaciated areas of the two continents. It is a well-known fact that in the present condition of the climates of the earth, the decrease in temperature as we rise above the sea is about 3° F. for each 1000 feet of altitude. Local circumstances may considerably affect this variation, but the range is not great. If glaciers were by the refrigeration of the climate restored to the surface which they occupied during the last ice period, we should expect to find the line of perpetual snow rising as we went southward about 3030 feet for each degree of latitude.

If, on an inspection of the areas glaciated during the recent ice epoch, we should find that this principle in the distribution of the glacier did not hold, we should apparently be justified in the supposition that the glacial climate was not due to greater cold than that which exists at present. Any departure from the normal rate of ascent of the perpetual snow-line in the region south of the glacier would be likely to throw some light on the climatal conditions prevailing during the time when the continental ice-sheets were developed.

Beginning our inquiry with the Appalachian section of Eastern America, we find there a region in many ways well suited for the determination we seek to make. The principal front of the ice stretched across the continent on a line which is now well determined. It is unmistakably evident that it crossed the valley of the Ohio at Cincinnati, and extended a little distance south of that stream into Kentucky. I have recently re-examined the evidence which goes to show the presence of the ice at the above named point, and have no doubt as to the goodness of the determination. At this point the surface of the country lies at a height at no point exceeding 900 feet above the level of the sea. From this position the level of the country gradually rises in a southerly direction until in the synclinal mountains near Cumberland Gap it attains a height probably exceeding 3500 feet. From this elevation the profile descends in the broad valley of the Upper Tennessee to about 1000 feet above the sea-level; thence it again rises until, in the mountains of North Carolina, we enter a field where many peaks rise to more than 6000 feet in height. From the front of the ice-sheet near Cincinnati to the central part of the North Carolina mountain district is about 200 miles. It is to be observed that the whole of this district is within the same great valley, and in a region where the isotherms at the present time follow each other with normal curves. We may therefore fairly conclude that, under the usual conditions of climate such as prevailed in North America, the ice-line should be found in the mountains of North Carolina at the height of 2000 feet above the base of the glacier at Cincinnati, or, say, at 3000 feet above the level of the sea. From that level to the top of the North Carolina mountains, or, say, for the height of 3500 feet, we should have indications of glacial conditions. A tolerably careful investigation of this country has shown me no evidence of ice action whatsoever, and all the other students of the subject who have visited this area have failed to find any facts which might afford even a supposition of glacial work in that field. I am therefore compelled to assume that the slope of the snow-line rose so rapidly from the ice-front at Cincinnati southward that it passed above the summits of these mountains.

If the elevation of western North Carolina was in the form of an isolated peak, we might have less confidence in this indication. But the district of land which should have lain much above the snow-level is some thousand square miles in area, a field sufficiently great to have developed very extensive glacial areas in case the peaks lay above the line of perpetual snow. The same considerations, though in a less accented way, are met when we examine the highlands of the Blue Ridge in Virginia, or the Alleghany Mountain district on the uplands of Virginia and West Virginia. A large part of the Blue Ridge in Virgina is high enough to have been the seat of glaciers, provided the snow-line were anywhere near the level of the glacial sheet where it crossed the existing Atlantic coast. The traces of glacial work in the Blue Ridge are extremely scanty. At the western extremity of Rock Fish Gap, immediately south of the Chesapeke and Ohio Railway, near its junction with the Shenandoah Valley Railway, there are accumulations which apparently are to be classed as glacial. This point is about 1600 feet above the level of the sea. If this accumulation be really of glacial origin, it apparently establishes the height of the ice-front in the Shenandoah, but as yet I must regard the indication as somewhat questionable. In the Alleghany Mountains west of Covington, Va., there are deposits which I am disposed to consider of a glacial nature. At this point the deposits lie about 2000 feet above the sea-level. These are the southernmost points at which I have found any satisfactory indications of glacial work, in the region south of the Potomac, and, until further investigated, both of these deposits must be regarded as of doubtful character.

In Europe, in the region south of the Alps, we find the facts similar in their character to those existing in North America. During the last glacial period the ice-sheet extended down on to the Italian plains, unquestionably attaining levels less than 1000 feet of altitude above the level of the sea, and probably occupying positions not more than 500 feet above that level. From my observations on the field I am disposed to think that the general mantle of the ice covered the southern face of the Alps down to within a few hundred feet above the sea. From 150 to 200 miles south of the Alps in the mountains of Tuscany, we have an extensive surface rising 4000 or 5000 feet above the sea. A careful search over much of this field showed me no evidence of occupation by ice. At the present rate of rise in the perpetual snow-line in Switzerland we should expect an ascent of that plane about 1500 feet in passing from the foot of the Alps to the Apennine Mountains north of Florence. We have thus a case similar to that we find in the North Carolina mountains, in which there are elevations just south of the continental glaciers of a sufficient height to have been covered by ice under normal circumstances, but where the evidence of such coating is conspicuously wanting.

I have endeavoured to apply the same considerations to the glacial phenomena of the Rocky Mountains, but the facts are as yet so imperfectly in hand that I have not been able to determine the relative altitude of the sheet in a satisfactory manner. This, however, may be said: the distinct glacial accumulations in Colorado probably do not extend below the level of 6000 feet. As this region is about on the parallel of the mountains of western North Carolina, it may perhaps indicate that the snow-line lay throughout the southern parts of the United States above the summits of the Carolina mountains. It seems to me, however, that in the existing state of our knowledge of the distribution of the glacial sheet in the Cordilleran section we cannot attach much importance to this evidence.

We have now to consider the possible explanation of the facts above adduced. Assuming that the relative height of the surface occupied by the glacier, when it crossed the Ohio River, and that of the region within two hundred miles south of it, even during the ice epoch,

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were what they are at the present day, it at first sight seems necessary to suppose that there was a rapid change in the temperature in passing from the ice-front towards the Gulf of Mexico. Before we adopt this consideration, however, we must bear in mind the fact that the ice-sheet of the last glacial period probably advanced for a considerable distance south of the perpetual snow-line, in substantially the same way in which an Alpine glacier descends in many cases to a depth of 1000 feet or more below the fields of enduring snow by which it is fed. Accepting the elevation of the continents as they now exist, and allowing 3° of temperature for each 1000 feet of altitude, it seems likely that the snow-line just touched the summit of the Carolina mountains and came to the surface of the sea near the southern end of Hudson's Bay. In other words, the protrusion of the ice to the south of this glacial snow-line carried it at a distance of near 1000 miles south of the gathering ground. This supposition, however, is of little value, for the reason that the level of the continent was clearly much disturbed during the glacial period, the surface declining to the northward within the glacial envelope, and probably rising to the southward of the ice-front.

It seems to me most likely that during the occupation of the northern part of the continent by glaciers, the southern portion of the continent was considerably elevated. All the streams which discharge into the ocean south of the former ice-front between New York and the Rio Grande show in their lower parts only moderate accumulations of alluvium which has been deposited since the close of the glacial period. They generally enter bays which appear to be the lower parts of gorges which were formed during the period when the area was more elevated than it is at the present time. These facts make it probable that if the mountains of North Carolina varied in elevation from the present height, they were more elevated than at this day. All the facts are against the supposition that we can explain the absence of glaciers in their highlands by supposing that the summits were lower during the ice period than they now are.

It seems to me we are compelled to suppose that the climate in the mountains of North Carolina, and probably in the great portion of the Apennine section south of the Alps, had during the glacial period a temperature not much if any lower than they have at the present time. As far as it goes, the evidence is thus opposed to the supposition that the glacial period was brought about by a general refrigeration in climate of the continents occupied by the sheet.

Within the basin of the Ohio, especially in the valleys of the Upper Tennessee system of waters, we find certain phenomena which lead us to the conclusion that the rainfall in a recent period, probably contemporaneous with the glacial epoch, was more considerable than at the present day. In many valleys which I have observed in that section the *débris* built into the imperfect alluvial plains is of a much coarser nature than that now brought down by the rivers. The channels bear the aspect of having recently been the seat of more voluminous streams than now occupy them. This evidence, gained from many points in the Southern Appalachians, leads me, independently of the hypothesis I am now suggesting, to the conclusion that during the last glacial epoch the rainfall of this country was much greater than it is at present. At Big Bone Lick in Kentucky, which lies within a few miles of the southern boundary of the ice-sheet, excavations made by me in 1868 show embedded in the deposits formed by the springs an abundant set of herbivorous mammals, including the mastodon and elephant, an extinct species of buffalo, and a musk-ox kindred to our Arctic species but of much larger size, a species of carabou, indistinguishable from our living American forms. The conditions of this deposit led me to suppose that these animals were probably not more ancient than the glacial period, and that they most likely occupied the surface during the time of abundant rainfall when the marshes were more extensive than at present, a period which if not exactly coincident with the extreme advance of the ice must fall within the glacial epoch.

The abundance of these large Herbivora, the relatively great size of the species, point also to the coincident occurrence of a rather abundant vegetation. If the period indicated by the massive gravels of the torrential streams and the Herbivora of Big Bone Lick be identical, and if this period coincides with the glacial period, as it appears to do, then we may fairly assume that the climatal conditions immediately to the south of the glacial sheet were not those of extreme cold. This evidence has nothing like the sure foundation obtained by the lack of glaciers in the mountains of North Carolina, but as far as it goes it confirms the results of those observations.

It is not my purpose, however, in the present writing to consider the perplexing question as to the cause of glacial climate. I desire only to call attention to the extent to which our glacial streams appear to have advanced, by what we may term forced marches, far to the south of the line of perpetual snow. Although the value of the evidence above noted cannot be determined until the matter has been more carefully brought together and abundantly discussed, the facts seem to me to militate against any hypothesis which seeks to account for the glacial period on the supposition that the climate in the glaciated regions was cooler than at present.

THE SUBJECT-MATTER OF EXACT THOUGHT.[1]

When mathematicians, logicians, and other exact thinkers think and reason, they think and reason about something. What is that something? And wherein consists the infinite variety which it presents? Is it a mere assemblage of detached subjects of entirely different natures? Or is it an harmonious whole, admitting of a definition and treatment which, though perfectly general, will yet preserve the essential characteristics of its component parts?

To judge by the usual habit of thought on these questions, we ought apparently to conclude that the former is the correct hypothesis; but that such a conclusion would be wholly erroneous, there can, I think, be no doubt whatever. The prevailing view is due, I believe, to the want of a proper appreciation of the difference between that which is the essential or necessary matter of exact thought, and that which, so far as the processes of reasoning are concerned, is merely the dress in which that necessary matter is clothed. This dress has, of course, a real importance of its own, and the study of it is not to be undervalued. But when we are investigating the subject-matter of exact thought it is not with it that we are concerned: it is not with the case, but with the works of the clock that we have to do; and thus our anxiety should be to get rid of the environments, to treat them as the "disturbing agents" of the experiments of the physicist, as likely to mislead, and therefore to be eliminated with the most scrupulous care.

That such dress exists in the case of every subject that we investigate is obvious enough; much of it is recognized

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[1] The object of this paper is to set forth in as simple and non-technical a manner as possible, the principles which were first formulated in my "Memoir on the Theory of Mathematical Form," published in the Philosophical Transactions of the Royal Society for 1886, vol. clxxvii. p. 1, and a "Note" thereon contained in the Proceeding of the Royal Society, vol. xlii. p. 193, which corrects the Memoir in some important particulars. The special applications of the theory principally dwelt on here are considered in detail in a recent paper by me, "On the Relation between the Geometrical Theory of Points and the Logical Theory of Classes," contained in the Proceedings of the London Mathematical Society, vol. xxi. p. 147. The mode of treatment of the whole subject adopted in the present communication must however be regarded as entirely new.—A. B. K.

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